

# PATENT SPECIFICATION

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## (54) FUEL CONTROL APPARATUS FOR GAS TURBINE ENGINE REHEAT SYSTEMS

(71) We, LUCAS INDUSTRIES LIMITED, formerly known as JOSEPH LUCAS (INDUSTRIES) LIMITED, a British Company, of Great King Street, Birmingham B19 2XF. 5 do hereby declare the invention for which we pray that a Patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

10 This invention relates to a fuel control apparatus for a gas turbine engine reheat system.  
According to the invention a fuel control 15 apparatus for a gas turbine engine reheat system includes a variable metering arrangement for controlling fuel flow to the engine reheat burners, a low pressure drain and a valve arrangement operable in one position 20 thereof to connect said metering arrangement to said burners, and in another position to connect said burners to said low pressure drain, said valve arrangement comprising first, second and third ports respectively 25 communicating with said metering arrangement, said burners and said drain, valve seats between said first and second ports and between said second and third ports, a closure member movable to selectively engage 30 said valve seats, means for biasing said closure member towards engagement with one of the seats, means responsive to a control signal to move said closure member against said biasing means into engagement 35 with the other of said seats, a dump valve between said third port and said low pressure drain, and means responsive to a further control pressure signal to open said dump valve.  
40 An example of a fuel control apparatus according to the invention will now be described with reference to the accompanying drawings:—

Figure 1 is a block diagram of the 45 apparatus as a whole,

Figure 2 shows diagrammatically a variable metering assembly forming part of the apparatus,

Figure 3 shows diagrammatically a servo pressure control arrangement forming part 50 of the apparatus,

Figure 4 shows a selector valve arrangement forming part of the apparatus,

Figure 5 shows diagrammatically a distributor arrangement forming part of the 55 apparatus,

Figure 6 shows diagrammatically a relay valve arrangement forming part of the apparatus,

Figure 7 shows diagrammatically a priming arrangement forming part of the 60 apparatus,

Figure 8 shows an alternative form of priming arrangement,

Figure 9 shows a further form of priming arrangement, and

Figure 10 shows yet another form of priming arrangement.

Referring firstly to Figure 1 the apparatus has a centrifugal vapour core fuel pump 70 10 driven by the engine. Pump 10 is of the kind which includes a throttle 11 responsive to a servo pressure signal PS1 applied via a passage 12 to increase pump delivery. This servo pressure signal PS1 is derived 75 in a manner later to be described. Throttle 11 is also responsive to a further servo pressure signal PS2 in a passage 13 which can oppose the pressure in passage 12.

A fuel metering assembly 14 includes an 80 electrical control arrangement 14a. The hydraulic parts of assembly 14 are shown in greater detail in Figure 2. Assembly 14 has an inlet 15 connected to the outlet of pump 10. Inlet 15 communicates via a non-return 85 valve 16 with three variable metering devices 17, 18, 19 arranged in parallel to regulate fuel flow to a primary burner 20. a gutter 21 and a colander 22 respectively of the engine reheat system (Figure 1). 90

The metering assembly 14 includes a first control means in the form of a three-dimensional cam 23 which is fixedly secured to the rod 24 of a piston 25. Cam 23 is formed with a series of profiles which 95 correspond to functions of compressor intake

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temperature  $T_1$  for a number of values of compressor delivery pressure  $P_2$ . Piston 25 is subjected on opposite sides to servo pressures derived from the pressure at the inlet 15. One side of piston 25 communicates via a valve 26 with a chamber 27 and also via a restrictor 28 with the downstream side of valve 16. Restrictor 28 and valve 26 thus provide a variable fluid pressure 10 potentiometer arrangement.

The other side of piston 25 communicates via a valve 29 with chamber 27 and also via a restrictor 30 with the downstream side of valve 16, valve 29 and restrictor 30 providing a further variable fluid pressure 15 potentiometer. Closure members for valves 26, 29 are provided by a single lever 31 movable in opposite directions by bellows 32, 33 respectively.

20 Bellows 32 is responsive to an air pressure intermediate a pair of restrictors 34, 35 and derived from the intake pressure  $P_1$  of the engine compressor. Bellows 33 is responsive to an air pressure intermediate 25 restrictor 35 and a further restrictor 36, and derived from the engine compressor delivery pressure  $P_2$ . A spring 37 is engaged between lever 31 and an adjacent end of piston stem 24. A further spring 38 is engaged 30 between lever 31 and an adjustable stop 39 on assembly 14. Chamber 27 communicates via an axial passage 40 in stem 24 with a further chamber 41 in which cam 23 is located. In use, for a given difference of pressure  $P_2$  and  $P_1$ , there will be a corresponding equilibrium position of piston 25, and hence a corresponding axial position of cam 23. Chamber 41 communicates with a low pressure connection 35 via a passage 185 and the sequence valve 40 90. Chamber 41 is thus maintained at a reference pressure  $PR$  which is substantially equal to this low pressure.

Cam 23 is mounted on a pinion 42 so 45 as to be axially slidable but non-rotatable relative to pinion 42. Pinion 42 meshes with a rack 43 which forms part of a piston 44. Piston 44 is responsive to the operation of an electrically operated servo-control 50 valve arrangement 45 having a pair of interconnected inlet ports 46, 47, and a pair of outlet ports 48, 49, and an exhaust port 50. Valve arrangement 45 includes electrical linear transducer 44a which is 55 responsive to the position of piston 44.

A valve spool 51 is axially movable in response to pressure signals at its opposite ends, these signals being derived from the pressure at port 47 by a nozzle 52 pivotally 60 movable by a torque motor 53 so as to be alignable with either of a pair of passages 54, 55 through which pressure signals are applied to the respective ends of valve spool 51.

65 The electrical signals from arrangement

14a which are applied to torque motor 53 are derived from the engine compressor intake temperature  $T_1$ , and the output from transducer 44a. The angular position of cam 23 is thus dependent on temperature  $T_1$ .

14 Variable metering devices 17, 18, 19 are angularly spaced about the axis of cam 23. In order that this arrangement may be portrayed diagrammatically in Figure 2, 75 a part of cam 23 is shown repeated adjacent the device 17.

Device 17 has a sleeve 60 with a port 61 which communicates with inlet 15. A piston control element 62 is slidable in sleeve 60 and includes a port 63 which operates with port 61 to provide a variable metering orifice. Control element 62 defines within sleeve 60 a chamber 64 which communicates with inlet 15 through a restrictor 65. Element 62 includes a stem 66 having a bore 67 which communicates with chamber 64. A ball closure member 68 is captive on stem 66 and provides a pilot valve which is operable to shut off bore 67.

90 A cam follower 69 is pivotally mounted on sleeve 60 and engages cam 23. Control element 62 is urged to the right, as seen in Figure 2, by the pressure  $DP_1$  downstream of ports 61, 63. This rightward movement is resisted by the pressure in chamber 64. If ball 68 is allowed to open in chamber 64, the servo signal pressure 100 by cam follower 69, the servo signal pressure in chamber 64 falls and element 62 moves to reduce fuel flow through device 17. With ball 68 shut the pressure in chamber 64 exceeds that downstream of ports 61, 63 and arrests element 62. Control element 62 thus acts as a follow-up servo piston 105 responsive to the position of cam follower 69, which is in turn responsive to pressure  $P_2$ , and temperature  $T_1$ .

110 Devices 18 and 19 are generally similar to device 17 and include respective piston control elements 70, 71. Elements 70, 71 are, however, also rotatable within their associated sleeves. An edge cam 72 is secured to a shaft 73 which extends into chamber 41. Cam followers 72a are keyed to the control elements 70, 71 and are 115 biased into engagement with cam 72. Shaft 73 is rotatable by a rack and pinion arrangement 74, controlled by an electrically operated servo-valve arrangement 75, identical with valve arrangement 45 described above. Electrical signals applied to servo-valve 75 are dependent on the position  $\theta$  of a power demand control for the engine. Control elements 70, 71 are thus responsive to pressure  $P_2$ , temperature  $T_1$ , 120 and control position  $\theta$ .

125 The fuel pressure  $DP_1$  immediately downstream of device 17 communicates via a passage 80 with a servo pressure control arrangement 81 (Figure 1) shown in 130

detail in Figure 3. The downstream side of device 17 also communicates with a throttle valve 82 which has a spring-loaded piston control element 83 responsive to pressure  $DP_1$ , and to a servo pressure  $S_1$  to regulate fuel flow from device 17 to provide a fuel pressure  $PF_1$  in an outlet passage 84. Servo pressure  $S_1$  is obtained in a manner later to be described and is applied 10 to element 83 via a passage 85.

Downstream of device 18 is a throttle valve 76 having an outlet 76a and a piston control element biased against the pressure  $DP_2$  downstream of device 18 by a spring 15 and by a servo pressure signal  $S_2$ , derived in a manner to be described and applied via a passage 77. Downstream of device 19 is a throttle valve 78 identical with valve 76 and having an outlet 78a. The piston control element of valve 78 is urged against the pressure  $DP_3$  downstream of device 19 by a spring and also by a servo pressure  $S_3$  derived in a manner to be described and applied via a passage 79.

25 Servo pressure control arrangement 81 has a valve spool 86 urged in one direction by the delivery pressure  $P_p$  of pump 10 and in the opposite direction by the pressure  $DP_1$  and 30 by a governor mechanism 87 responsive to the engine speed. Valve spool 86 is coupled by a torsionally stiff spring 88 to an auxiliary piston 89 whose side remote from spool 86 communicates via a sequence valve arrangement 90 (later to be described) and via passage 13 with the pressure  $PS_2$  on pump throttle 11. Auxiliary piston 89 and spool 86 slide in a sleeve 91 provided with ports 92, 93 which respectively communicate with pressure  $PS_2$  and with pump delivery pressure  $P_p$ . The ports 92, 93 are axially spaced by less than the length of piston 89 so that at the rightward end of its travel (as seen in Figure 3) piston 89 45 is subjected on both sides to pressure  $PS_2$ , and at the leftward end of its travel to pressure  $P_p$  on both sides. The force due to the difference between pressures  $P_p$  and  $PS_2$ , and applied via spring 88 to spool 86, 50 is thus limited.

Sleeve 91 also has a port 94 communicating with pressure  $PS_1$  via passage 12, a port 95 communicating with a servo pressure  $PS_3$ , derived via valve arrangement 55 90, a port 96 communicating with a low pressure  $LP$ , which is conveniently the output pressure of a boost pump, not shown, in a fuel tank associated with the engine. Port 94 communicates with the bore of 60 sleeve 91 via a pair of restricted passages. The arrangement is such that in a mid-position of spool 86 both port 95 and port 96 communicate with port 94 via the respective restricted passages, which thus act 65 as a fluid potentiometer.

An increase in pump delivery pressure  $P_p$  urges spool 86 to the left, permitting increased flow between ports 94, 96 and decreased flow between ports 94, 95. If servo pressure  $PS_3$  is high, servo 70 pressure  $PS_1$  falls and throttle 11 in pump 10 moves to reduce fuel flow. This movement causes a fall in pressure  $PS_2$  which is transmitted via valve arrangement 90, whereby piston 89 is urged to the right to 75 oppose movement of spool 86. Piston 89 thus provides a feedback of the position of the pump throttle 11 until pump delivery pressure  $P_p$  has risen sufficiently to restore an equilibrium condition. An increase in 80 engine speed  $N$  or in pressure  $DP_1$  similarly causes pump delivery pressure  $P_p$  to be increased. Pump delivery pressure  $P_p$  at inlet 15 of metering assembly 14 is thus varied to maintain the difference between 85 the pressures  $DP_1$  and  $P_p$  substantially constant for a given engine speed, this pressure difference being variable with engine speed. The weights 87a of the governor mechanism 87 have a relatively low specific gravity, 90 whereby, when a denser fuel is used, the effect of engine speed on spool 86 is reduced.

Sleeve 91 includes a further port 97 which is normally in communication with port 95 95, but which is shut off by the valve spool 86 when the latter has moved sufficiently to the right to shut off port 96 from port 94, this latter being the condition shown in 100 Figure 3.

Arrangement 81 also includes a spool valve 100 having a spool 101 responsive to pressure  $DP_1$ , and to pressure  $DP_2$  which is obtained, as above described, from metering assembly 14 and opposes 105 pressure  $DP_1$ . Surrounding spool 101 is a sleeve 102 having a port 103 communicating with pump delivery pressure,  $P_p$ , a port 104 communicating via 110 passage 77 with throttle valve 76 in metering assembly 14, to apply servo pressure  $S_2$  thereto, and a port 105 communicating with port 97 and hence normally with low pressure.

A piston element 106 is coupled to spool 115 101 by a torsionally stiff spring 107. By virtue of leakage around piston element 106 the latter acts as a dashpot to slow movement of spool 101.

A further spool valve 110 is substantially 120 identical with valve 100 and has a spool 111 movable in response to pressure  $DP_1$  and to a pressure  $DP_3$  obtained, as above described from the downstream side of metering device 19 in arrangement 14, to 125 control the value of servo pressure  $S_3$  at a port 112. Port 112 communicates via passage 79 with throttle valve 78 in arrangement 14.

Spools 86, 101, 111 and governor 87 are 130

4 rotated via a gear train by a shaft 113 driven by the engine.

5 Associated with metering assembly 14 is a shuttle valve arrangement 120, shown diagrammatically in detail in Figure 4. Arrangement 120 comprises a pair of shuttle valves 121, 122 having respective ball control members 123, 124. Valve 121 is connected by passages 125, 126 to pressures PF2, PF3 on the downstream sides 10 of the respective throttle valves 76, 78 in assembly 14. Valve 123 has an outlet 127 which forms one inlet of valve 122. The other inlet of valve 122 communicates via 15 a passage 128 with the pressure PR in chamber 41 in assembly 14. The outlet of valve 122 communicates via a passage 129 with throttle valve 82 in assembly 14. The pressure in passage 129 provides servo 20 pressure S1. Pressure S1 is thus equal to whichever of pressures PR, PF2 or PF3 is the largest.

25 When the engine reheat system is in use, fuel is supplied by the pump 10 to the assembly 14 and passes via the device 17 and throttle valve 82 to passage 84, and thence via a distributor arrangement 130, later to be described in detail with reference to Figure 5, to the primary burners 30 20 of the reheat system.

35 The output pressure  $P_p$  of pump 10 is controlled as above described to maintain pressure DP1 substantially constant for a given engine speed and fuel density. A rise in pressure DP1 urges spool 101, in arrangement 81, to the right, causing the value of pressure S2 to rise towards pump delivery pressure  $P_p$ . Throttle valve 76 progressively closes until pressure 40 DP2 has risen to equal DP1, restoring equilibrium conditions. Similarly, a rise in pressure DP2 moves spool 101 to the left, pressure S2 falls, and throttle valve 76 opens until equilibrium is restored. Spool 45 valve 110 in arrangement 81 operates similarly to maintain pressure DP3 equal to pressure DP1.

50 Valve 82 in metering assembly 14 acts as a pressurising valve. The springs in valves 76, 78 provide only light pre-loads to ensure that these valves are shut when the system is closed down. The spring in valve 82 is such that, in the absence of servo pressure S1, 55 pressure DP1 is just sufficient to operate the spools 86, 101, 111 in the servo pressure control arrangement 81. At low flows, therefore, the system pressure is low and pumping power loss is a minimum.

60 At higher rates of reheat fuel flow, pressure PF2, PF3, increase, and the highest of the pressures PF2, PF3 and the reference pressure PR is applied via the shuttle valve arrangement 120 to provide servo pressure 65 S1. Servo pressure S1 assists the spring in

valve 82 to raise the system pressure. The consequent rise in pressure DP1 increases the values of servo pressures S2 and S3 to enable throttle valves 76, 78 to maintain the increased system pressure.

70 At a low value of reheat fuel flow, i.e. at low values of compressor delivery pressure  $P_2$  and of angle  $\theta$  of the power demand control the pressure in chamber 64 of valve 17 becomes equal to the reference pressure PR in chamber 41, and if in excess of DP1 will urge valve 17 fully shut. Pressures PF2 and PF3 are also low. In these circumstances servo pressure S1 becomes equal to 80 pressure PR in chamber 41 of arrangement 14. The system pressure is thereby maintained high enough to prevent pressure PR, which acts on the stems of control elements 62, 70, 71 in the respective metering devices 17, 18, 19 from urging these 85 control elements to positions in which reheat fuel flow is shut off.

85 The distributor arrangement 130, shown in Figure 5 has a housing 131 with inlet ports 132, 133, 134 respectively connected 90 with the outlet passages 84, 76a and 78a respectively of throttle valves 82, 76, 78. Associated with the respective inlet ports 132, 133, 134 are outlet passages 135, 136, 137 which respectively communicate with 95 the primary burner 20, gutter 21 and colander 22 of the engine reheat system.

95 Between the inlet ports and their associated outlet passages are respective valve arrangements 138, 139, 140 which are operable to connect outlet passages 135, 136, 137 either to their associated inlet ports or to a gallery 141 which communicates via a fourth valve arrangement 142 with a low pressure drain outlet 143.

100 Valve arrangement 140 comprises a pair of frusto-conical seats 144, 145 in the housing 131. A dumb-bell-shaped control member 146 has part spherical end portions 147, 148 respectively engageable with seats 144, 145. Member 146 is biased by a spring 149 in a direction to engage portion 147 with seat 144 and thereby to isolate inlet port 134 from outlet passage 137. In this position of control member 146 outlet passage 110 137 communicates with gallery 141.

110 Member 146 is movable against spring 149 by an axially aligned piston 150 responsive to servo pressure PS3 in a further gallery 151 within the housing 131. Supply 120 of pressure PS3 to gallery 151 is controlled, in a manner to be described, by sequence valve arrangement 90, and by a relay valve 160 (Figure 1) to be described with reference to Figure 6. Pressure PS3 is of sufficient magnitude that control element 146 is readily movable against spring 149 and the pressure in inlet port 134. Valve arrangement 140 thus has a "bang-bang" action.

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5 a sleeve 152 forming part of housing 131. Portion 148 is radially movable with respect to piston 150. Control element 146 is thus self aligned with the valve seats 144, 145.

5 5 Valve arrangements 138, 139 are substantially identical to valve arrangement 140, differing only in their dimensions. Arrangements 138, 139 are also responsive to servo pressure PS3 in gallery 151.

10 10 Valve arrangement 142 has a frusto-conical seat 153 with which a part-spherical closure member 154 is engageable. Valve arrangement 142 is biased shut by a spring 155 and is movable against spring 155 by a piston 156 in response to a servo pressure PS4, also derived via sequence valve arrangement 90.

15 15 Sequence valve 90 is shown diagrammatically in Figure 1 and comprises a sleeve having a plurality of ports. Within the sleeve is a control element rotatable by the shaft 73 (Figures 1 and 2) to selectively interconnect the ports. As shown in Figure 1 the control element has a number of metering edges which co-operate with the associated ports so as to interconnect only those ports shown associated with a particular metering location on the control element. Rotation of the control element 20 is best considered as being in five anti-clockwise steps, B to F, from an initial position A as seen in Figure 1. Four metering locations 170, 171, 172, 173 are shown.

20 20 25 25 30 30 35 35 40 40 45 45 A high pressure source, conveniently the delivery pressure of the engine main fuel pump, is connected to ports 174, 175 at metering locations 170, 171 respectively. Ports 176, 177 at location 170 are respectively connected to passage 13 of pump 10 and to the PS2 connection of pressure control arrangement 81. Thus in positions A and B ports 174, 176 are interconnected and in positions C to F ports 176, 177 are interconnected.

50 50 55 55 60 60 65 At metering location 171 port 175 is connected to a port 178 in position A only, and to a port 179 in positions C to F. In position B ports 178 and 179 are isolated from the port 175. The pressure at port 179 provides servo pressure PS3, and that at port 178 provides servo pressure PS4. The low pressure LP referred to above is connected to ports 180, 181 at metering locations 172, 173 respectively. A further port 182, at location 172, is connected to port 178, the arrangement being such that pressure PS4 is at high pressure in position A and at low pressure in positions B to F. A port 184 at location 172 is connected to port 179 at location 171, so that pressure PS3 is a low pressure in positions A and B. A port 183 at location 173 is connected to the outlet of the pump 10, 65 so that the pump outlet is connected to low pressure in position A only of the control element.

70 70 75 75 80 80 85 85 90 90 95 95 100 100 105 105 110 110 115 115 120 120 125 125 130 130 The positions A to F of the shaft 73, and hence of the sequence valve control element, correspond to positions of a pilot's control lever (not shown) for the engine. Positions A and B correspond to an inoperative condition of the reheat system, movement between positions B and C corresponds to light-up or shut down of the reheat system, depending on the direction of movement, and positions D to F correspond to different levels of reheat flow as controlled by cam 72 (Figure 2).

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tributor arrangement 130. Passage 211 communicates with the side of the piston head 206 which is remote from that subjected to pressure  $P_p$ .

5 Piston 201 has an internal bore which communicates with ports 218, 219, 220 in the wall of piston 201. In the extreme rightward position of piston 201 as seen in Figure 7, ports 218, 219, 220 are clear 10 of the respective annular passages 209, 210, 211. The permitted travel of piston 201 is such that ports 218, 219, 220 communicate with respective passages 209, 210, 211 to supply fuel to the distributor arrangement 15 130. In the extreme leftward position of piston 201 the ports 218, 219, 220 are again clear of the respective annular passages. In this leftward position pump delivery 20 pressure  $P_p$  communicates with a passage 221 connected to a "hot-shot" ignition device 222 (Figure 1) of a known type.

The rate at which piston 201 moves leftward, and hence the quantity of fuel delivered to each reheat burner is dependent 25 on the size of restrictor 208. The piston 201 is maintained in its leftward position by pump delivery pressure  $P_p$  so long as the reheat system remains operative. When the reheat system is shut down pressure  $P_p$  30 becomes effectively equal to the pressure at the pump inlet, and the piston 201 is returned to its initial position by spring 203.

Device 222 is of a known type and is 35 responsive to pressure  $P_p$  in passage 221, when servo pressure  $PS_3$  in passage 193 is high, to supply a measured quantity of fuel to nozzles 223, 224, which are respectively in the engine combustion chamber and downstream of the engine turbine, thereby applying a flame jet to the reheat burners 20, 21, 22 to ignite the reheat system.

In use, with sequence valve in position 45 A, high pressure will be applied to passage 13 of pump 10 and throttle 11 will be urged fully shut. Pressure  $PS_4$  will be high, opening valve 142 to connect gallery 141 in distributor 130 to the drain 199 through passage 143.  $PS_3$  will be low, allowing fluid 50 in passages 135, 136, 137 to be dumped to drain 199, via valves 138, 139, 140 and outlet 143 in distributor 130. The low value of  $PS_3$  ensures, via pressure control 55 arrangement 81, that servo pressure  $PS_1$  is also low, and movement of throttle 11 to reduce pump delivery is not therefore opposed. The pump outlet is connected to the low pressure via sequence valve 90. The 60 reheat system is thus shut down.

When sequence valve 90 is moved to position B, pump passage 13 remains at high pressure and  $PS_3$  remains at low pressure.  $PS_4$  however, falls to a low pressure, 65 shutting off the dump valve 142, in dis-

tributor 130. The pump outlet is also isolated from low pressure. Position B of valve 90 is thus a position prior to lighting the reheat system. Valves 138, 139, 140 and 70 142 are shut, and this condition may be maintained as long as required in readiness for operation of the reheat system.

When valve 90 is moved to position C, pump passage 13 is isolated from high pressure and connected to pressure control 75 arrangement 81 to provide servo pressure  $PS_2$ . Pressure  $PS_3$  becomes high, enabling pressure  $PS_1$  to rise to increase pump output pressure. Relay valve 160 is energised to apply  $PS_3$  to distributor 130 and open 80 valves 138, 139, 140 to permit fuel flow to the reheat system. Fuel from pump 10 is delivered via passage 205 to priming device 200, from which measured quantities of fuel are discharged via passages 215, 216, 85 217 and distributor 130 to the respective burners 20, 21, 22.

When the priming valve arrangement 200 completes its priming operation, hot-shot device 222 is enabled, by virtue of 90 pressure  $PS_3$  to ignite the reheat system via nozzles 223, 224. Priming arrangement 200 completes its operation during the time in which metering assembly 14 starts to deliver fuel to the reheat system.

Subsequent rotation of shaft 73 to position F by rack and pinion 74 (Figure 2) in response the position  $\Theta$  of the engine power demand control, does not affect the operation of valve 90, but causes metering 100 arrangement 14 to increase fuel flow to the engine.

Figure 8 shows a form of priming valve arrangement, which is an alternative to that shown in Figure 7. This alternative form has a piston control member 230 which is movable within a bore 231 against a spring 232 by pump delivery pressure  $P_p$ , applied via passage 205. Annular passages 233, 234, 235 surround piston 230 within bore 231 and respectively communicate, via non-return valves 212, 213, 214, with the passages 215, 216, 217. Valves 212, 213, 214 are identical to the correspondingly numbered valves described 110 with reference to Figure 7. Ports 236, 237, 238 extend through the wall of piston 230, as before. A chamber 241 on the side of piston 230 remote from passage 205 communicates via a flow restrictor 239 and a 115 non-return valve 240 with low pressure. Chamber 241 also communicates with passage 233 via a restrictor 242.

In use, piston 230 is moved, as before, against spring 232 by pressure  $P_p$  so that 125 ports 236, 237, 238 move past passages 233, 234, 235 to deliver measured quantities of fuel to the reheat system. At the rightward extent of its travel piston 230 uncovers passage 221 which communicates, 130

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as before, with the "hot-shot" device 222. The rate at which piston 230 moves, and hence the quantity of fuel delivered to each burner, is dependent on the size of restrictor 242. Piston 230 is maintained in its rightward position, while pressure  $P_p$  is applied to passage 205, by the low pressure in chamber 241 resulting from leakage to low pressure via non-return valve 240 and 10 restrictor 239.

The further form of priming arrangement shown in Figure 9 has a piston 250 movable against spring 251 by pressure  $P_p$ . The rate of movement of piston 250 is 15 dependent on the rate of flow through a restrictor 252. An annular passage 253 communicates with passage 205 and piston 250 has a single port 254 which co-operates with passage 253 to deliver a measured 20 amount of priming fuel to the reheat burners, as before. Delivery of fuel to the burners is via the non-return valves 212, 213, 214 and respective passages 215, 216, 217 described above.

25 A fuel control apparatus which includes the device of Figure 9 does not include a hot-shot ignition device 222. Instead, piston 250 includes a pair of passages 255, 256 which are respectively operable, after 30 piston 250 has moved to complete its priming function, to connect the high pressure source to nozzle 223 in the engine, and to connect passage 205 to nozzle 224 in the engine. Connections to nozzles 223 and 35 224 are made via respective spring-loaded valves 257, 258. Valves 257, 258 are also biased shut by the low pressure  $L_p$ .

In use, after piston 250 has moved sufficiently to the right to complete the priming operation, passage 255 permits high pressure flow to nozzle 223. Piston 250 continues to move to the right, shutting off the above high pressure flow after approximately .25 seconds. Shortly after the high 45 pressure flow has begun, passage 256 permits fuel at pump delivery pressure  $P_p$  to flow to nozzle 224. At the extreme rightward position of piston 250 both the passages 255, 256 are clear of their associated 50 ports and flow to nozzles 223, 224 ceases. Piston 250 is maintained in its rightward position as a result of fuel leakage to a low pressure via a restrictor 258.

The alternative form of priming valve 55 arrangement shown in Figure 10 includes a piston-like control member 260 slideable in a cylinder 261 and biased by an extension spring 262 towards a stop 263. Pump outlet 15 communicates with cylinder 261 via passage 205 and a restrictor 264 so that 60 the delivery pressure of pump 10 opposes spring 262. Outlet 15 also communicates with an annular passage 265 communicating with the bore of cylinder 261 and 65 closed by member 260 when the latter is

against stop 263. Member 260 has ports 266 which can communicate with passage 265 as member 260 is moved against the bias of spring 262. The permitted travel of member 260 is such that in its extreme 70 rightward position, as seen in the drawing, ports 266 are again clear of passage 265. In this position member 260 uncovers the passage 221 which in this case interconnects cylinder 261 and the ignition device 75 222.

Downstream of control member 260 cylinder 261 communicates via non-return valves 212, 213, 214 with passages 215, 216, 217. The upstream side of valves 212, 213, 214 communicate, via a restrictor 267 and a further non-return valve 268, with the inlet of the pump 10. Valve 268 is such that it lifts off at a relatively low pressure.

In use, piston member 260 is moved, as 85 before, against spring 262. Ports 266 first move into alignment, and subsequently out of alignment, with passage 265. As ports 266 move past passage 265 fuel flows via non-return valves 212, 213, 214 and respective 90 passages 215, 216, 217 to the distributor 130. As this fuel flow increases, the consequent reduction in pressure at pump outlet 15 causes throttle 11 to be moved to maintain the output flow. As ports 266 move 95 past their mid-position relative to passage 265, the pump output pressure tends to increase and is again corrected. A small amount of fuel flows back to the pump inlet via restrictor 267 and relief valve 268.

100 With member 260 in its rightward position, flow through passages 215, 216, 217 ceases and passage 221 is uncovered to cause device 222 to ignite the reheat system. Since there is now no flow through ports 105 266, the pressure immediately upstream of valves 212, 213, 214 falls to a low value. Control member 260 is thus maintained in its rightward position so long as the delivery pressure of pump 10 is sufficient to overcome spring 262. Pump delivery pressure is, in fact, maintained by the servo pressure signal in passage 12 in response to engine operating parameters as above described.

115 When the reheat system is shut down, the pump delivery pressure becomes effectively equal to pump inlet pressure and the member 260 is returned to its initial position by spring 262.

The arrangement shown in Figure 10 120 enables a priming fuel charge to be supplied to the reheat burners substantially immediately reheat is selected, the time taken being typically less than one second, this time being effectively dependent on the 125 size of restrictor 264.

The foregoing fuel control apparatus is also shown and described, and aspects thereof are claimed, in our co-pending patent applications Nos. 15881/72 (cognate with 130

28999/72), 29000/72, 29001/72 and 33843/75 (Serial Nos. 1 423 361, 1 423 363, 1 423 364 and 1 423 365).

5 WHAT WE CLAIM IS:—

1. A fuel control apparatus for a gas turbine engine reheat system, including a variable metering arrangement for controlling fuel flow to the engine reheat burners, 10 a low pressure drain and a valve arrangement operable in one position thereof to connect said metering arrangement to said burners, and in another position to connect said burners to said low pressure drain, said valve arrangement comprising first, second and third ports respectively communicating with said metering arrangement, said burners and said drain, valve seats between said first and second ports and between said second 15 and third ports, a closure member movable to selectively engage said valve seats, means for biasing said closure member towards engagement with one of the seats, means responsive to a control signal to move said closure member against said biasing means into engagement with the other of said seats, a dump valve between said third port and said low pressure drain, and means responsive to a further control pressure signal to 20 open said dump valve.
2. An apparatus as claimed in Claim 1 in which said control signal is a pressure signal, and said control signal responsive means comprises a piston element.
3. An apparatus as claimed in Claim 2 in which said closure member is responsive to said control signal to connect said metering arrangement to said burners, and which includes means, responsive to a requirement 25 to light the reheat system, for providing said control signal.
4. An apparatus as claimed in Claim 3 in which the means for providing said signal

comprises a selector valve responsive to the position of an engine power demand control. 45

5. An apparatus as claimed in Claim 4 in which said selector valve is operative to remove said further control pressure signal, and thereby to close said dump valve before providing the first-mentioned control signal 50 to connect said metering arrangement to said burners.

6. An apparatus as claimed in Claim 5 which includes a relay valve operable to apply the first-mentioned pressure signal to 55 said third port, whereby when said dump valve is moved in response to said further control pressure signal to connect said third port to said low pressure drain, the first-mentioned pressure signal falls to a low 60 value.

7. An apparatus as claimed in any preceding claim in which said metering arrangement includes first, second and third metering orifices responsive to engine operating 65 parameters to control fuel flow to respective ones of the engine reheat burners.

8. An apparatus as claimed in Claim 7 in which said valve arrangement comprises a plurality of first ports respectively communicating with said first, second and third metering orifices, a plurality of second ports respectively associated with said first ports and communicating with respective ones of said reheat burners, a plurality of third ports 70 associated with respective groups of first and second ports and commonly connected to said low pressure drain, and a plurality of closure members.

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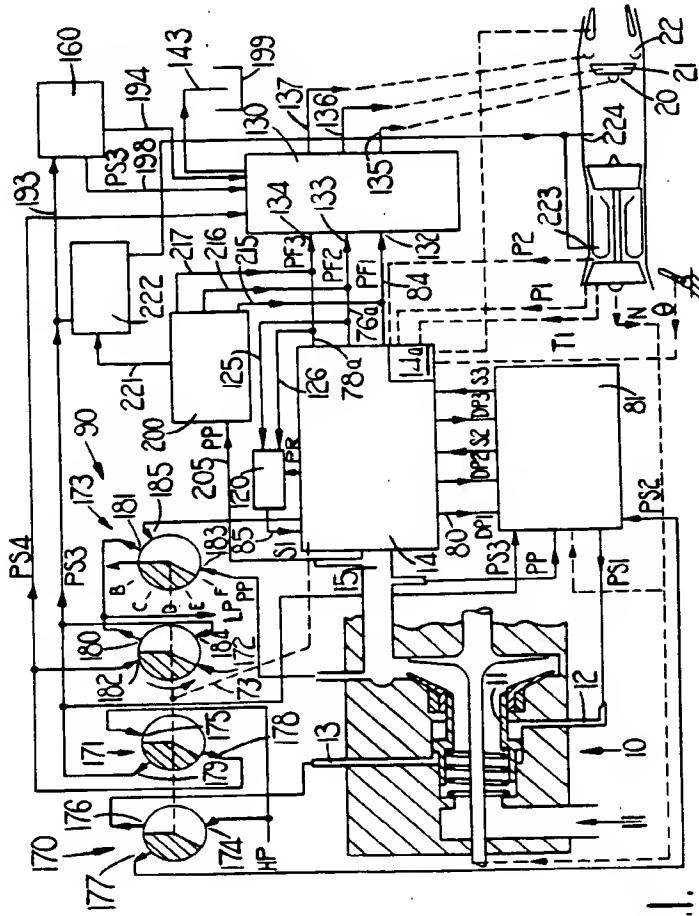
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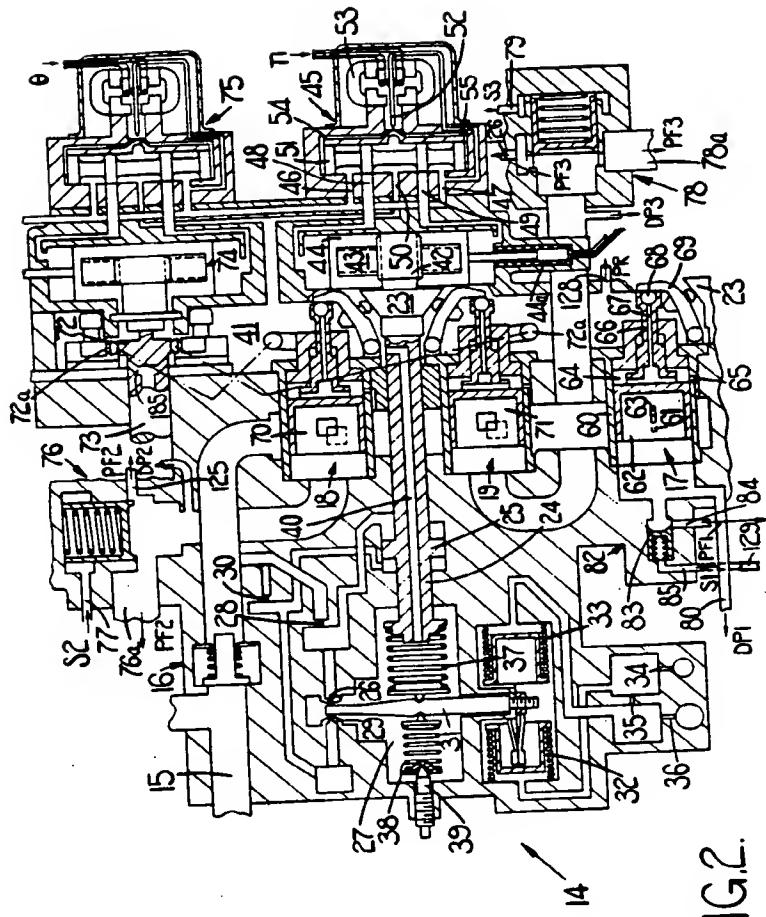
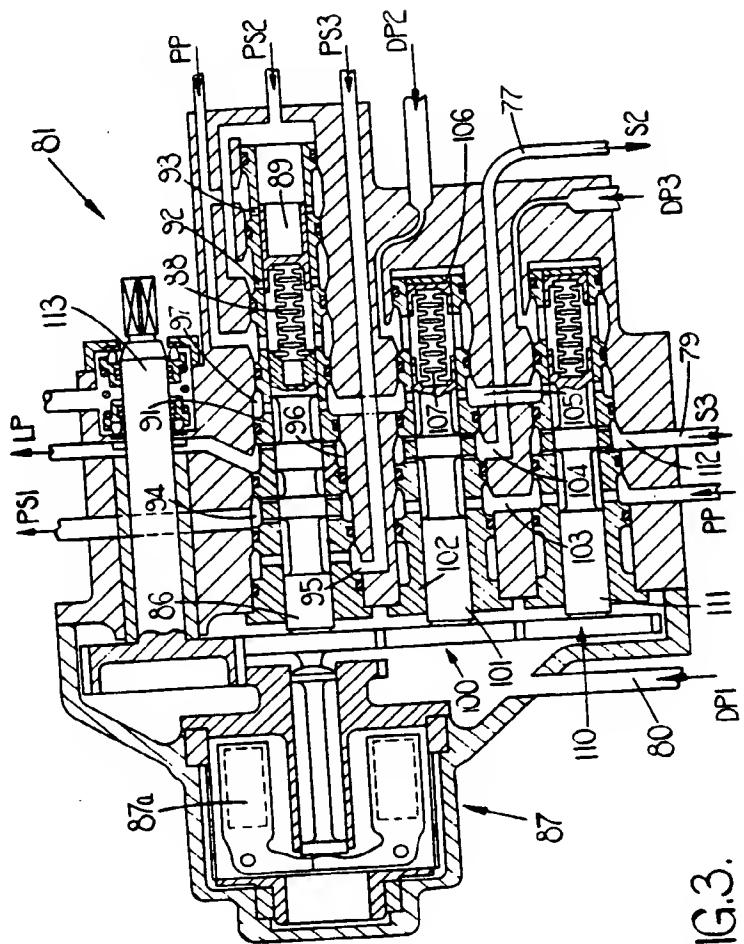


FIG 2.

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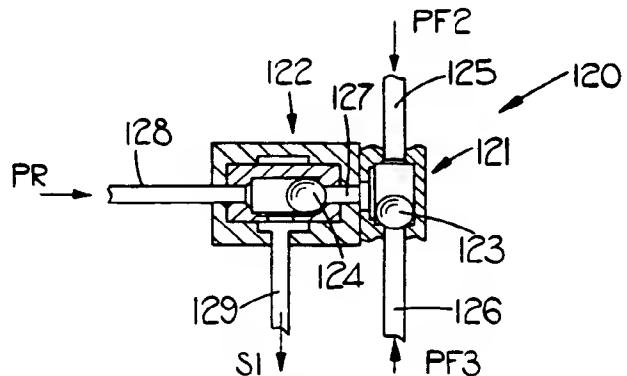


FIG. 4.

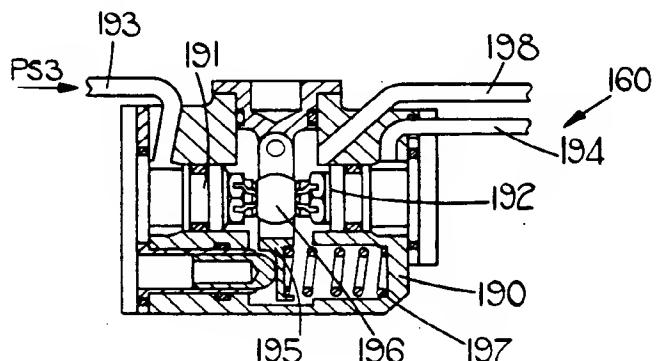


FIG. 6.

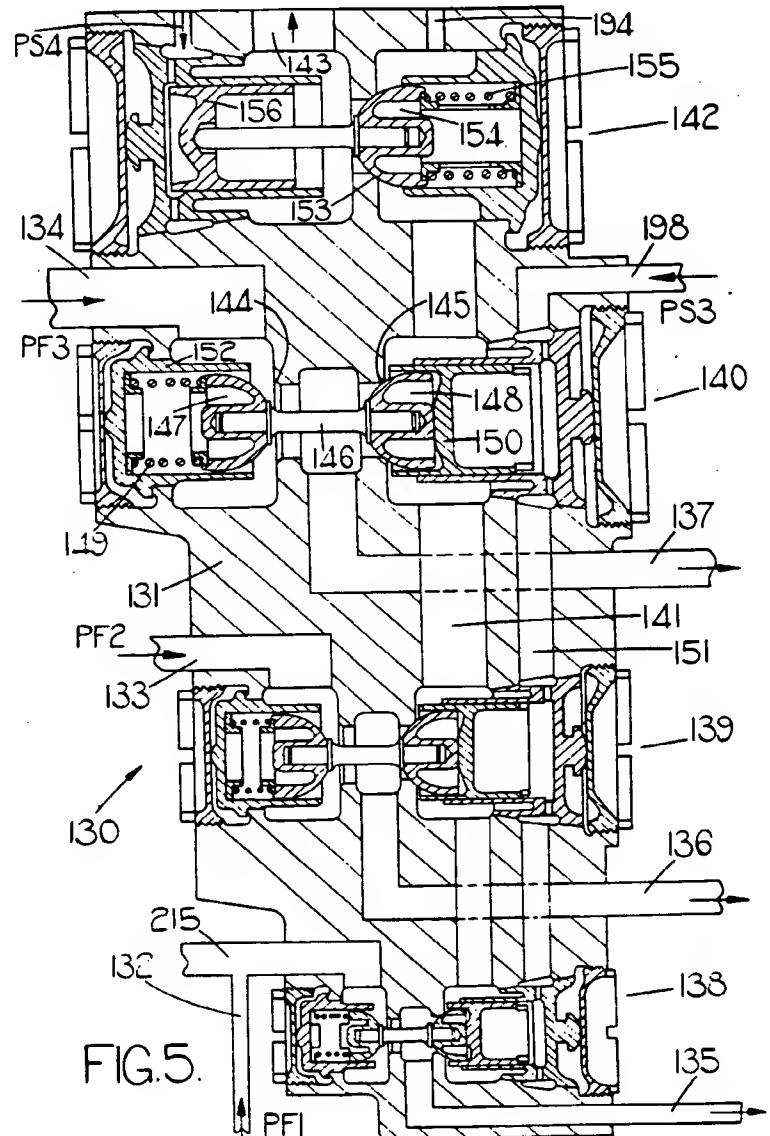
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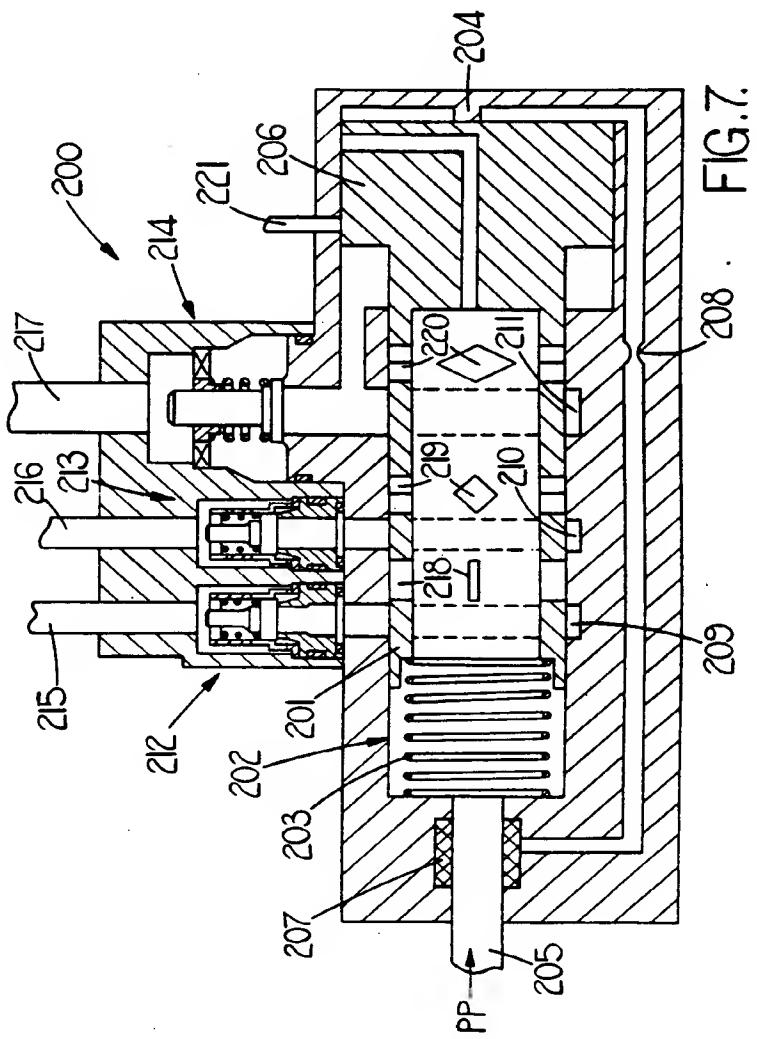
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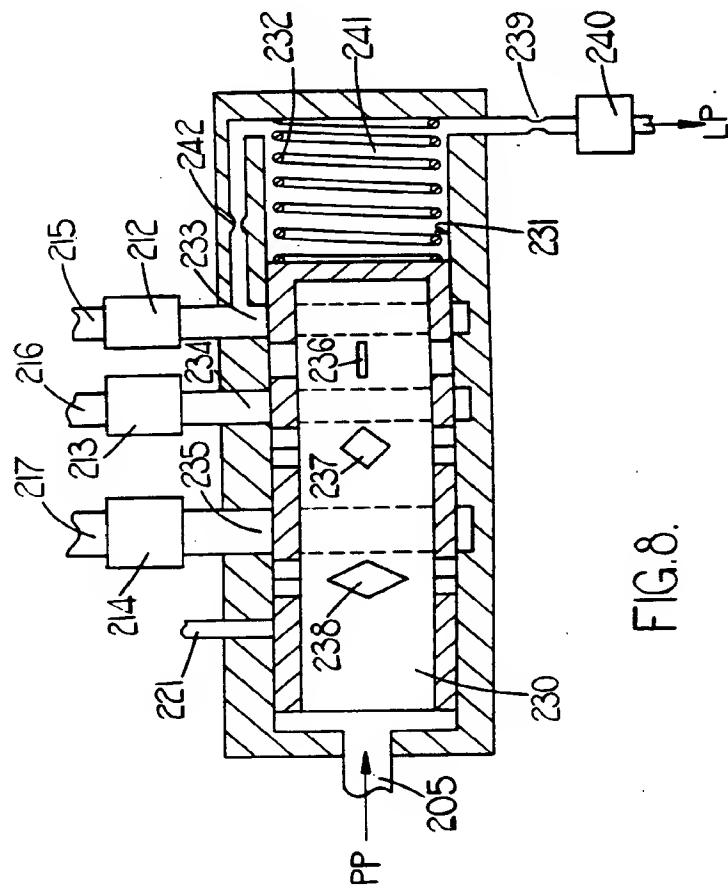


FIG. 8.

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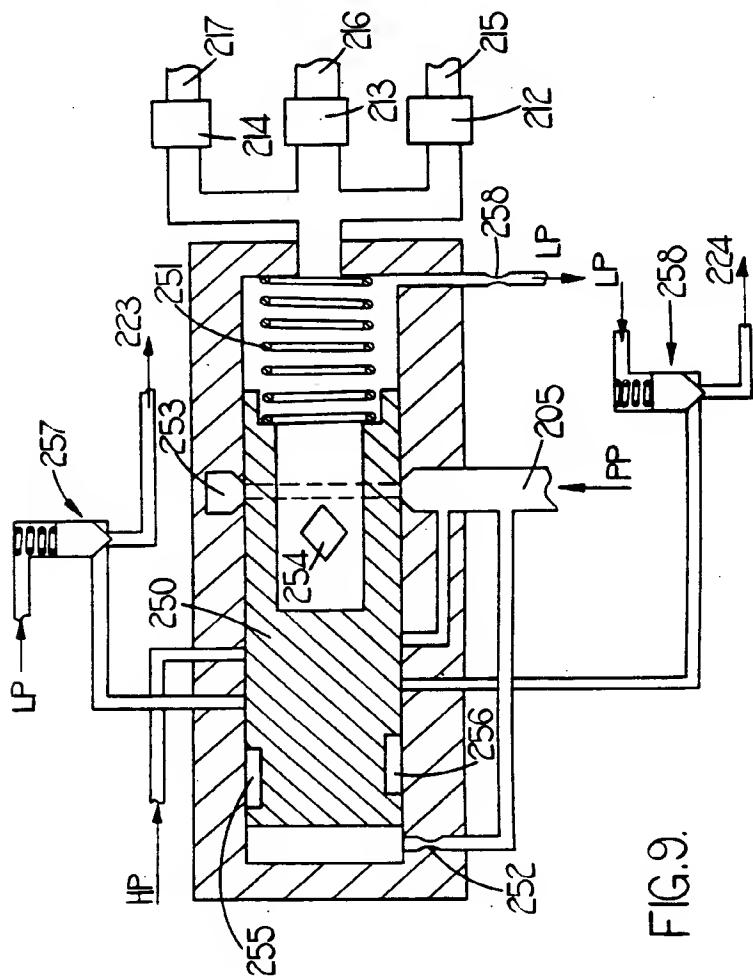


FIG. 9

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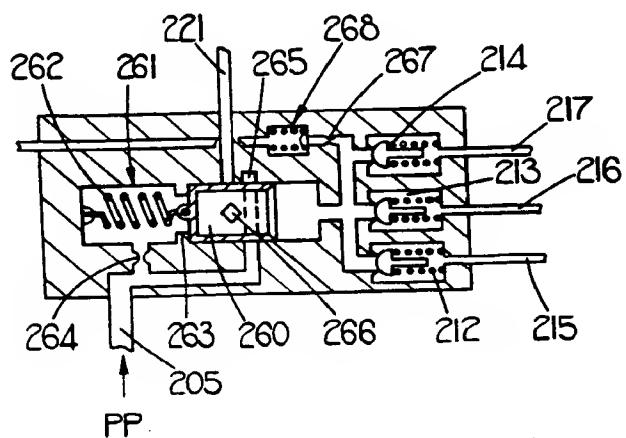


FIG. 10.

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